INFESTATION CHARACTERISTICS of the BALSAM WOOLLY APHID in the Pacific Northwest

By Russel G. Mitchell

PACIFIC NORTHWEST
FOREST & RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE

U.S. FOREST SERVICE
Research Paper PNW-35

1966

Contents

Introduction

The balsam woolly aphid, *Adelges (=Chermes) piceae* (Ratzeburg), is one of the most inconspicuous insect pests in the woods. Because the aphid itself is so tiny and the damage accumulates gradually over a period of years, the insect's presence often goes unnoticed. However, the aphid's size and method of attack is not a measure of its importance. In the Pacific Northwest, the aphid has demonstrated considerable ability to kill and damage three species of our native true firs. In a period from about 1950 to 1957, more than a billion and a half board feet of commercial-sized sawtimber was killed or seriously weakened in a 400,000-acre area in southwestern Washington (Pope 1958). Additional unmeasured damage has occurred since 1957.

Early recognition of damage caused by the balsam woolly aphid can result in considerable savings of timber. Stands suffering the greatest damage can be scheduled for early logging. This paper aims to aid the forester and landowner by describing (1) some distinguishing characteristics of the aphid and its damage and (2) the nature of balsam woolly aphid infestations as related to its three principal hosts in Oregon and Washington--Pacific silver fir (*Abies amabilis* (Dougl.) Forbes); subalpine fir (*A. lasiocarpa* (Hook.) Nutt.); and grand fir (*A. grandis* (Dougl.) Lindl.). Information is also presented on the susceptibility of 15 other species of *Abies*--exotic and native--growing in the Pacific Northwest.

History of the Aphid

The balsam woolly aphid is widely distributed throughout Europe and North America, infesting only the true firs (*Abies* spp.). The insect is native to western Europe, where the principal host is European silver fir (*A. alba* Miller), a tree that suffers little or no damage from the aphid. It was introduced into North America about 1900, probably entering eastern Canada on nursery stock near the southern end of Nova Scotia (Balch 1952). From there, and possibly another introduction point in Maine, the aphid spread over extensive areas of the Maritime Provinces and New England States, killing and damaging thousands of acres of balsam fir (*A. balsamea* (L.) Mill.). In 1957, the pest was also discovered in southeastern United States, infesting Fraser fir (*A. fraseri* (Pursh) Poir.) (Speers 1958).

The first record of the balsam woolly aphid on the west coast of North America was in 1928 (Annand 1928). The aphid was observed infesting noble fir (*A. procera* Rehd.), grand fir, and the European silver fir in and near San Francisco, California. In 1930, significant damage to grand fir in Oregon's Willamette Valley marked its appearance in the Pacific Northwest (Keen 1938). The true seriousness of the pest became apparent in 1957 when forester M. M. Grobin

found the aphid killing Pacific silver fir stands around Mount St. Helens in Washington (Johnson and Wright 1957). Further searching the same year revealed the aphid also present in subalpine fir, in both Oregon and Washington. By 1957, an estimated 600,000 acres of forest in the two States were infested by the balsam woolly aphid (Whiteside 1958). Since then, aphid infestations have also been found on Pacific silver fir near Vancouver, British Columbia, and on grand fir on Vancouver Island (Silver 1959).

Aphid Distribution in Oregon and Washington

The balsam woolly aphid has spread along the summit and west side of the Cascade Range from the middle fork of the Snoqualmie River in Washington to Crater Lake National Park in Oregon. The principal host in the mountains is subalpine fir, but extensive infestations in Pacific silver fir stands are found at lower elevations in Washington, particularly in the vicinity of Mount St. Helens and around Mossy Rock and Morton. Isolated areas of infestation in Pacific silver fir are also found in the coastal mountains near Grand Ronde, Oregon, and west of Centralia, Washington. In the lowlands, the aphid infests grand fir throughout Oregon's Willamette Valley and into Washington as far north as Olympia. Infestations on exotic plantings have also been noted in Bremerton and Auburn, Washington, suggesting that the aphid is probably dispersed throughout the Puget Sound area. Infestations in grand fir have been observed in the valley bottoms of most Oregon coastal streams, from Astoria in the north to Coquille in the south.

Appearance and Biology of the Aphid

The balsam woolly aphid may be as small as 1/75 of an inch in length when newly hatched; maximum adult size seldom exceeds 1/25 of an inch. Viewed through a microscope, the adult is purple to black, wingless, and almost spherical. It is ordinarily concealed beneath a white, woollike secretion, which also covers a clutch of amber-colored eggs (fig. 1). Except for the newly hatched crawler stage, all forms resemble the adult and live out their lives anchored to one spot on the bark surface. The new crawler stage, in contrast, is amber colored, long legged, and very active.

The balsam woolly aphid has two generations per year throughout most of its range, though in lowland valleys there may be as many as four generations per year (Mitchell et al. 1961). Aphid populations in the Pacific Northwest are composed wholly of females, thus increasing efficiency of reproduction by

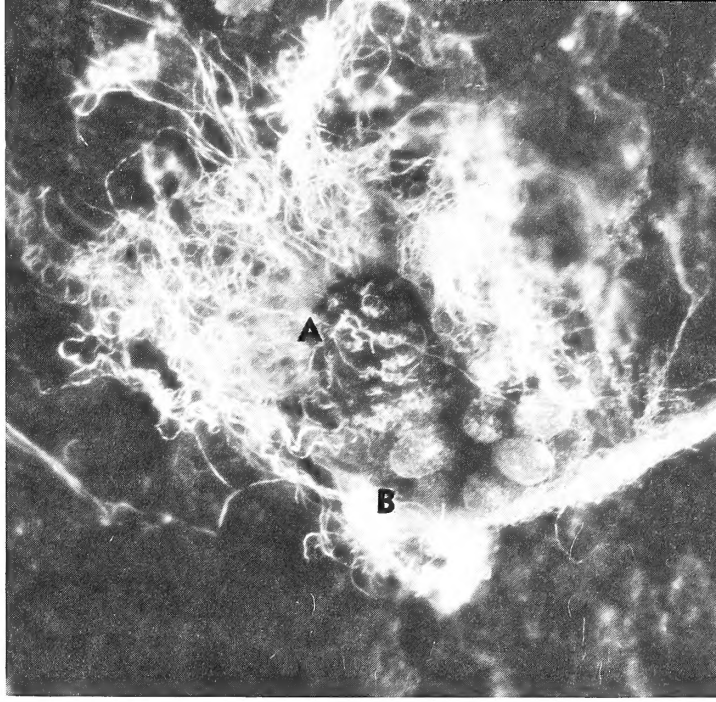

Figure 1.--Magnified view (36X) of feeding adult aphid (A) and eggs (B). Woolly secretion pushed aside for photographing.

eliminating the necessity of mating. Some 30 to 100 eggs are laid by an adult, permitting a theoretical production of 900 to 10,000 progeny in a two-generation year. In warm weather, eggs hatch within a few days after being laid, and the new crawlers seek out a place to feed. The site selected may be close to the place of hatching or it may be on another tree. Dispersal to other trees appears to be accomplished largely by wind. Once a suitable location has been selected, the insect inserts its long, threadlike mouthparts into the living bark and starts feeding (fig. 2).

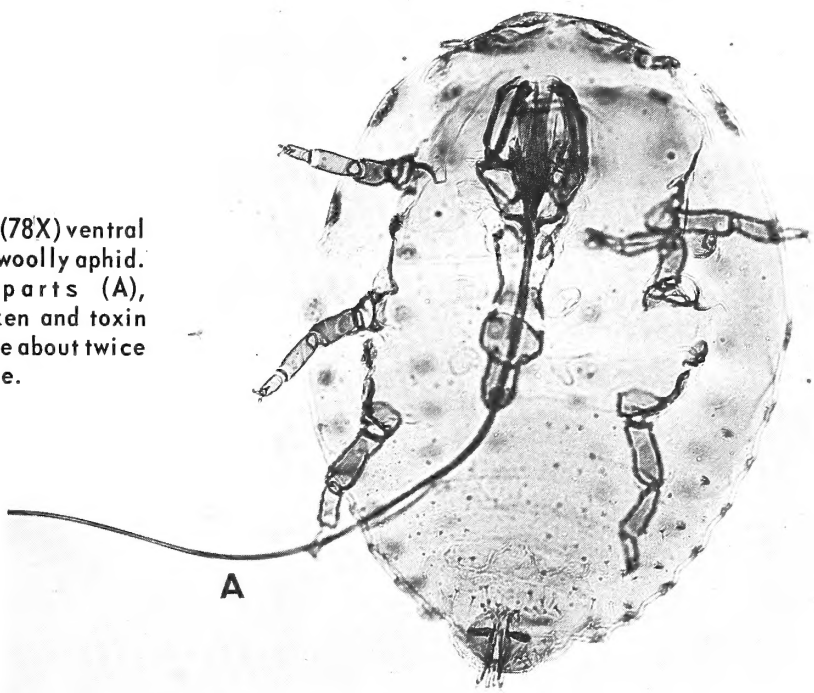

Figure 2.--Greatly enlarged (78X) ventral view of an adult balsam woolly aphid. The threadlike mouthparts (A), through which food is taken and toxin injected into the host, are about twice as long as illustrated here.

Nature of Aphid Damage

When the aphid feeds, it pumps a salivary substance into the tree (Balch et al. 1964). The saliva is toxic and produces abnormal reactions in the cells of the cambium and differentiating tissues of the phloem and xylem (Doerksen and Mitchell 1965). Cellular damage is always localized within a few millimeters of where the aphid feeds. Accordingly, the amount of damage to a tree depends not only on the size of the aphid population but also where it is located. Populations concentrated in the outer portions of the tree's crown cause less damage than populations on the main stem and large branches.

Symptoms of a crown infestation are swelling of the outer nodes and terminal buds (called "gouting" in the literature), and inhibition of new growth (figs. 3, 4, and 5).

Figure 3.--Gouting by balsam woolly aphid settling along the twig and around flower buds. Typical of upper crown on large trees, especially around staminate flowers (subalpine fir).

Figure 4.--Gouting by the balsam woolly aphid settling around nodes and on lenticels of stem. Typical on suppressed trees (subalpine fir).

The swelling is caused by an increased production of thick-walled xylem cells and enlargement of phloem and bark cells. The result is that shoot growth is inhibited or halted entirely. This loss of new growth, coupled with natural shedding of old needles, results in a crown that becomes increasingly thin and less effective in its photosynthetic function. A persistent infestation of this type can kill a tree, but the decline is slow.

With a stem attack, the most conspicuous evidence is often the aphid itself; population densities of 20 or more aphids per square inch appear as a whitish, cottony film on the bark (fig. 6). Other symptoms are formation of compressionlike wood in the xylem (fig. 7) and an abnormal cell arrangement in the phloem and cortex. Precisely how the cellular response affects tree health is unclear, though indications are that both water and food movement are impaired. Whatever the effect, the response is rapid; heavy stem infestations have been known to kill trees in 3 years.

Figure 5.--Gouting by balsam woolly aphids settling only around the buds and annual nodes. Typical on trees with smooth internodal bark (grand fir).

Figure 6.--Stem infestation of the balsam woolly aphid on subalpine fir, about 75 aphids per square inch.

Figure 7.--Compressionlike wood (rotholz) produced in grand fir in response to 7 years of stem infestation.

Infestation Characteristics on Native Firs

The character of infestations and their effects differs markedly with different species. These differences are probably nowhere more apparent than in the Pacific Northwest where there are three hosts of the aphid, sometimes growing in mixture and occupying a great variety of sites. Descriptions of some of these characteristics and reactions are presented below.

Grand fir

Of the three Pacific Northwest hosts, grand fir is the most resistant to the balsam woolly aphid. It has been known to endure infestations as long as 15 years, and though growth loss and defect due to abnormal wood may be considerable, probably no more than 20 to 30 percent of the infested trees die. Damage is caused largely by bole infestations. Injury stemming solely from gouting-type crown infestations is rare.

Trees are first susceptible to attack when they are about 15 years old, with the largest, most vigorous trees infested first. Stem infestations are most abundant and mortality is greatest in the 25- to 35-year age class, when dominant and codominant trees are about 8 to 10 inches d.b.h. Sporadic infestations and some mortality also occur in older age classes, but these are mostly reinfestations of trees that survived infestations in earlier years. It appears that most trees over 45 years old in the Willamette and coastal valleys have been infested at one time or other.

Infestations on grand fir usually start on the lower 5 feet of the main stem. After 2 to 5 years of feeding, the aphids gradually exhaust the bark of available nutrients, and the population moves upward. A portion of the bark just below the surface dies, and a resin-impregnated, wound layer develops. During the change, the bark turns black and usually is accompanied by a heavy resin flow, as shown in figure 8. The resin comes largely from callous areas on the underside

Figure 8.--Resinosis on grand fir from prolonged stem attack by the balsam woolly aphid.

of limbs and where limbs join the main stem (fig. 9). Later, as the tree grows, the bark develops fissures, and the resin hardens. The cracks in the bark permit aphids to reinfest the areas previously abandoned.

Figure 9.--Callous areas from aphid infestation on the basal portion of grand fir limbs.

Often, the first characteristic of crown decline is a drooping of the terminal 10 to 15 feet of the crown (figs. 10 and 11); eventually, often during the first winter, the top breaks off. Typically, the lower limbs become infested and develop distress symptoms before those in the upper crown; thus, infested grand fir often appears to be dying from the bottom upwards.

Figure 10.--Top-curl from balsam woolly aphid infestation on grand fir.

Figure 11.--Top-curl from infestation on subalpine fir. Down-crook at end of limbs is also characteristic.

Also, because the less vigorous internodal branches succumb rather quickly, there is a general impression that the tree is dying from the inside out. As the infestation moves upward, the abandoned lower limbs often show some recovery, particularly with open-grown trees. After several years, if the tree is still alive, the population reaches the top, and the upper limbs are killed or severely damaged. Then the tree appears to die from the top down. Figures 12a and 12b (pictures of the same tree taken 5 years apart) show the final stage of decline.

Figure 12.--Open-grown grand fir in the last stages of decline from infestation by the balsam woolly aphid. A was photographed in 1957; B, in 1962.

Grand fir stands appear uniformly susceptible on the west side of the Cascade Range. But, grand fir growing along the top and on the east side of the Cascades generally appears immune to the aphid, even when intermingled with infested subalpine fir. In such situations, the immune grand firs may become gouted, but the gouts disappear after the aphids eliminate the susceptible subalpine fir.

Subalpine fir

Subalpine fir is the most sensitive of the three hosts to balsam woolly aphid. Trees can be killed in 3 years by stem infestations, though 4 to 5 years is more common. In some stands, up to 90 percent of the firs were killed in about 5 years, mostly by stem infestations. Mortality resulting solely from gouting-type crown attacks is insignificant.

Subalpine fir reaches susceptible age at about 25 years, with the most vigorous trees being the most attractive to the insect. Infestations appear first on open-grown and stand-edge trees, then on dominants and codominants within the stand. They then often spread quickly to the smaller suppressed trees, which seem capable of enduring an infestation longer than the larger ones. Nevertheless, many understory trees are killed by the aphid, death doubtless hastened somewhat by the effects of suppression.

Stem infestations on subalpine fir typically start high on the tree (about midcrown) and work down, a reverse of the pattern on grand fir. First evidence of damage is usually most evident at the top of the tree. Sometimes the upper third or more of the crown will be killed and turn red. Often, there will be distinctive lack of new growth in the uppermost lateral limbs, giving the last few feet of the crown a pinched-in appearance. Also, terminal growth is usually sharply reduced and the last 1 or 2 feet at the top develop a distinct lean, about 45° off vertical (fig. 11). As the aphid population moves down the stem, the symptoms of decline occupy an increasingly larger part of the crown.

Most trees die within 1 year after the infestation reaches ground level; some sooner. Often, trees are killed in stages--a third or half the crown one year; the remainder the next year. Just as often, the entire crown dies, turning a straw color, then red, as if the bole were girdled. The bark abandoned by the aphid turns black or coppery. Resinosis is sometimes associated with the last stages of decline but is not as common or as conspicuous as with grand fir.

Significant gouting always accompanies the decline of subalpine fir but ordinarily is not conspicuous because the trees die so quickly. The most apparent gouting in a stand is usually on trees without stem infestations, particularly the suppressed, understory trees. The gouting population is supplied by the infested overstory. Gouts become large because the aphids supplied are usually abundant enough to produce swellings but insufficient to cause rapid death.

The most susceptible subalpine fir stands appear to be those on the best sites--stream bottoms, benches, around meadows. Also, the greatest damage occurs at the lowest elevations, starting about 3,000 feet. Boggy sites where subalpine fir grows in mixture with Engelmann spruce (*Picea engelmannii* Parry) are especially susceptible. Open stands, such as those where subalpine fir invades old lava beds, or slide areas, are also quite susceptible. The least susceptible stands are those on low-site hillsides and at high elevations, near timberline. Infestations are rarely found on trees at elevations above 5,500 feet, although at Crater Lake, near the southern end of the tree's range, infestations have been found as high as 6,000 feet.

Pacific silver fir

Infestation characteristics of the aphid on Pacific silver fir are similar to those on subalpine fir. The important difference is that silver fir is not as susceptible--fewer trees are infested and more recover from attack. Also, the less lethal, gouting-type, crown attack is more common than stem attacks in Pacific silver fir. Nevertheless, Pacific silver fir is subject to stem infestations and can be killed quickly, within 3 to 4 years by heavy populations. In a severe outbreak, tree mortality may approach 70 percent of the stand (Johnson et al. 1963). Even trees 4 to 6 feet in diameter are killed.

The pattern of stem infestations on Pacific silver fir is rather unpredictable. Sometimes infestations start low on the stem and move upwards; sometimes it is the reverse. Generally, when infestations exist on the lower bole, they are found on trees that have smooth, white bark extending all the way to the ground. Trees enter the period of susceptibility as young as 50 years. The largest, most vigorous trees are usually the first to be infested and suffer the most damage.

Symptoms of decline in Pacific silver fir are seldom spectacular. Though red-top trees may occur in areas of heavy stem infestation, decline is generally more subtle. Lack of new growth and an attendant change in color to a blackish green in the upper crown are the usual first symptoms that the woolly aphid is present. Conspicuous gouting, followed by loss of old needles, occurs next. Gradually the top dies, usually without conspicuous needle fade. As the infestation persists, the damaged area occupies an increasingly larger proportion of the crown.

A stem infestation accelerates the rate of decline, sometimes suppressing characteristics such as gouting. But if only a crown population is present, the decline can be quite prolonged, with damaged trees changing very little in appearance from year to year. Mortality in this type of attack ordinarily is not severe, but the loss in growth is thought to be considerable. Details of decline in Pacific silver fir are illustrated and described in a previous publication (Johnson et al. 1963).

Infestations in Pacific silver fir are most common and most severe on the best sites and at lower elevation zones (e.g., below 3,000 feet in southwest

Washington). Within the lower zones, stands along stream bottoms and on bench areas usually have the largest number of stem infestations and suffer the most mortality. Silver fir near the upper elevation zones of its range is seldom attacked, regardless of site. Of hundreds of Pacific silver fir observed growing in stands where subalpine fir was being heavily killed by the balsam woolly aphid, only three trees have been found to have stem infestations. Silver fir is gouted in these situations, but the gout disappears soon after the outbreak on subalpine fir collapses. The article by Johnson et al. (1963) discusses in more detail the effect of site on the susceptibility of Pacific silver fir.

Relative Susceptibility of Other True Fir Species

The effect of natural infestations of the woolly aphid was also studied on 15 other species of *Abies* growing in natural stands, arboretums, and ornamental plantings. Observations distinguished whether: (1) the trees were supporting stem or crown infestations, (2) gouting was evident, and (3) trees were being killed. In general, studies suggested that North American firs are very sensitive to the woolly aphid. Oriental species were next in degree of sensitivity, and European firs were barely affected. Table 1 lists 18 native and exotic true firs observed supporting natural balsam woolly aphid infestations in the Pacific Northwest.

Noble fir, Veitch fir (*A. veitchii* Lindley), and white fir (*A. concolor* (Gord. & Glend.) Lindl.) had light-to-moderate infestations; all others had moderate-to-heavy stem and crown infestations. The population on noble fir was too light, in fact, to reliably rate its sensitiveness. However, there are two references in the literature of noble fir in exotic plantings (one each in western Europe and California) killed or seriously damaged by the balsam woolly aphid (Annand 1928; Francke-Grosmann 1938).

Two Sakahlin firs died, but their death must be regarded with some suspicion. The trees were seriously weakened by the aphid and appeared near death when sprayed with a 1/8-percent emulsion of benzene hexachloride in water. One month later both trees were dead, suggesting a possible phytotoxic reaction. However, two other infested Sakahlin firs (in less serious condition) were sprayed and did not die. When sectioned, the main stems of the dead Sakahlin firs displayed a "rotholz" condition in the outer annual rings, a symptom of aphid attack usually associated with North American trees.

Noble fir, Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.), and white fir were also observed in natural stands associated with subalpine fir that was being killed by heavy populations of the balsam woolly aphid. In every case the associated firs became gouted, yet there were no instances of bole infestation or serious damage to noble fir or white fir. Gouting ceased and growth returned to normal when the population died on subalpine fir. Observations on Shasta red fir have not yet followed a cycle to the end of an outbreak, but evidence suggests that it, too, will resist aphid attack.

Table 1.--Damage severity of 18 species of *Abies* found naturally infested with balsam woolly aphid in the Pacific Northwest

Tree species	Tree origin	Damage			
		Severe[1/]	Moderate[2/]	Slight[3/]	Nil[4/]
Abies lasiocarpa (Hook.) Nutt. Subalpine fir	Western North America	X	--	--	--
A. fraseri (Pursh) Poir. Fraser fir	Eastern U.S.	X	--	--	--
A. balsamea (L.) Mill. Balsam fir	Northeastern North America	X	--	--	--
A. amabilis (Dougl.) Forbes Pacific silver fir	Northwestern North America	X	--	--	--
A. grandis (Dougl.) Lindl. Grand fir	Western North America	--	X	--	--
A. lasiocarpa var. *arizonica* (Merriam) Lemm. Corkbark fir	Southwestern North America	--	X	--	--
A. magnifica var. *shastensis* Lemm. Shasta red fir	Western U.S.	--	X	--	--
A. koreana Wilson Korean fir	Korea	--	X	--	--
A. sachalinensis Masters Sakhalin fir	Northeastern Asia	--	X	--	--
A. religiosa Lindley Sacred fir	Southern Mexico	--	--	X	--
A. procera Rehd. Noble fir	Western U.S.	--	--	X*	--
A. concolor (Gord. & Glend.) Lindl. White fir	Western U.S.	--	--	X*	--
A. alba Miller European silver fir	Western Europe	--	--	--	X
A. cephalonica Loudon Grecian fir	Greece	--	--	--	X
A. pinsapo Boissier Spanish fir	Spain	--	--	--	X
A. sibirica Ledebour Siberian fir	Northern Asia	--	--	--	X
A. firma Siebold and Zuccarini Momi fir	Japan	--	--	--	X
A. veitchii Lindley Veitch's silver fir	Japan	--	--	--	X

*Moderate to light infestations.

1/ Trees often killed; gouting severe.

2/ Gouting moderate to severe; trees occasionally killed.

3/ Gouting moderate to light; trees not observed killed.

4/ Gouting not apparent; trees not killed.

Discussion and Conclusions

The characteristic infestation symptoms, discussed in the foregoing sections, suggest certain procedures for aiding the forester in detecting the balsam woolly aphid before significant damage occurs. In general, detection involves three procedural steps:

1. Look for the right stand.--Because some stands are more susceptible than others, much fruitless searching can be avoided if the first effort is directed to areas where the aphid is most likely present. Type maps and topographic maps should help in the selection of stands. First priority should be those stands in the lower elevation zones, since they are generally the most susceptible. In Oregon and southern Washington, the susceptible zones are: Grand fir, below 1,000 feet; Pacific silver fir, 1,500 to 3,000 feet; subalpine fir, 3,000 to 5,500 feet. Next priority should be to the high-site stands growing along stream bottoms and on flat, benchy areas. Particularly close scrutiny should be given subalpine fir around the margins of mountain meadows and in mixture with Engelmann spruce. Finally, stand age should be a priority. The most susceptible age for grand fir is between 25 and 35 years, but older trees are also infested. Pacific silver fir must be over 50 years old (usually much older) and subalpine fir more than 25.

2. Look for the aphid.-- The whitish film of a stem infestation (including populations on the larger limbs) is the most conspicuous feature of an outbreak in its early stages. Stem infestations are usually associated with smooth-barked, fast-growing trees. Infestations on grand and Pacific silver fir are usually apparent on the lower 10 to 15 feet of the stem, but may not be uniformly distributed. Suspected trees should be examined closely on all sides. Because infestations on subalpine fir typically start high on the stem, the observer must study the upper part of the bole as well as the lower. Binocular field glasses are a valuable aid.

3. Look for damage.--When making surveys, one should look for damage as well as the aphid. A tree displaying suspicious symptoms should be the first tree examined for stem infestation. Similarly, during the search for stem attacks, understory trees, fallen branches, and wind-thrown trees should be examined for gouting. One should also look for trees with sections of bark that are unusually black and show heavy resin flow on the main stem. Trees with red tops, open crowns, or reduced terminal growth deserve close attention. Grand firs with tops broken out or with drooping leaders should be prime suspects.

Aerial surveys are ineffective for early detection of balsam woolly aphid outbreaks. One detects infestations from the ground, walking through the forest looking at individual trees. The best time for searching is in late September or

in October. At this time, stem infestations are at their peak density and red-topped trees are most abundant.

The forester, having determined that he has a problem, may wish to establish a logging schedule to reduce damage. The priorities listed by Johnson, Mitchell, and Wright (1963) are suggested as a guide. In brief, they are (in order of priority) to: (1) cut stands containing a large number of dead trees; (2) cut stands with a preponderance of trees with moderate-to-serious crown damage; (3) cut stands containing bole-infested trees; (4) cut stands containing a predominance of large, overmature trees; and (5) cut stands on high-site areas.

After having cut the susceptible old growth, the forester may decide to substitute apparently aphid-resistant true firs for the susceptible species. The author suggests that in light of the present knowledge, such a decision would be unwise. Several North American species of *Abies*, of which noble fir is a good example, have demonstrated that their degree of resistance is altered when they are grown outside their native environment. With foreign species, growth characteristics for timber production are generally unknown. A number of exotic *Abies* species have recently been outplanted in the Oregon Cascades to test both aphid resistance and growth performance. Until at least preliminary findings from these studies are known, sizable investments by forest-land managers in exotic plantings would be a decided gamble.

It appears that the forester's best policy would be to encourage resistant and immune tree species already growing in aphid-infested areas. Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) grow well below 3,500 feet, where grand and Pacific silver fir suffer severely from the balsam woolly aphid. At higher elevations, where subalpine fir is attacked, Pacific silver fir, noble fir, and Shasta red fir have displayed resistance to the woolly aphid and will thrive on well-drained sites. Mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) also grows well on most high-elevation sites. On difficult sites--around swamps, avalanche areas, and lava beds--lodgepole pine (*Pinus contorta* Dougl.) and Engelmann spruce could be encouraged.

Summary

The balsam woolly aphid is an introduced pest and probably the most serious enemy of true firs in the Pacific Northwest. Infestations in Pacific silver fir, grand fir, and subalpine fir stands have caused considerable tree mortality and growth loss over a wide area of western Oregon and Washington. But the aphid is so tiny and the damage accumulates so gradually that presence of the aphid often goes unnoticed. To find infestations, a forester must know where to look and what to look for. This is especially true if he is to detect the aphid in time to salvage dead and dying timber.

The three susceptible tree species differ markedly in their degree of sensitivity to the balsam woolly aphid. Subalpine fir is most easily killed, often dying after only 3 to 4 years of heavy infestation. Grand fir is rather tolerant to aphid attack and can survive 15 years or more of continuous infestation. Pacific silver fir is between grand and subalpine firs in susceptibility: On poor sites, it is quite tolerant to the aphid; on good sites, it can be as sensitive as subalpine fir.

It is possible with all three host species to characterize, in general terms, the sites where aphid outbreaks are apt to be most severe:

1. Most balsam woolly aphid infestations are found west of the summit of the Cascade Range. Infestations in subalpine fir may extend 2 to 3 miles east of the summit, but rarely farther.

2. The most severe outbreaks occur at the lower ends of the host species' elevation ranges--from about 3,000 to 5,500 feet in subalpine fir; 1,500 to 3,000 feet in Pacific silver fir; and below 1,000 feet in grand fir.

3. Stands along stream bottoms and in flat, benchy areas (i.e., good sites) are highly susceptible to attack. Subalpine fir is especially susceptible around meadows, avalanche areas, and lava beds.

Noble fir, Shasta red fir, and white fir are other native true firs that have been damaged and even killed by the balsam woolly aphid. However, the affected trees were growing out of their natural environment--as ornamentals or in arboretums. The same species have demonstrated resistance to the woolly aphid when growing in natural stands. True firs from Europe and Asia are also infested by the aphid in the Pacific Northwest, but are generally undamaged by the attack.

Varying degree of aphid susceptibility of true fir stands on different sites offers hope for survival of such highly susceptible species as subalpine

fir. But moving relatively immune species such as noble fir into new areas can increase their susceptibility to balsam woolly aphid attack. The best management policy at the present time in areas affected by the aphid is to encourage resistant and nonsusceptible species already growing on the site--Douglas-fir and western hemlock below 3,500 feet; Engelmann spruce, lodgepole pine, mountain hemlock, noble fir, Shasta red fir, and Pacific silver fir at higher elevations.

Literature Cited

Annand, P. N.
1928. A contribution toward a monograph of the Adelginae (Phylloxeridae) of North America. 465 pp. Palo Alto, Calif.: Stanford Univ. Press.

Balch, R. E.
1952. Studies of the balsam woolly aphid, *Adelges piceae* (Ratz.) and its effects on balsam fir, *Abies balsamea* (L.) Mill. Can. Dep. Agr. Pub. 867, 76 pp.

_____ Clark, J., and Bonga, J. M.
1964. Hormonal action in production of tumours and compression wood by an aphid. Nature (Lond.) 202: 721-722.

Doerksen, Allan H., and Mitchell, Russel G.
1965. Effects of the balsam woolly aphid upon wood anatomy of some western true firs. Forest Sci. 11: 181-188, illus.

Francke-Grosmann, H.
1938. Über *Dreyfusia piceae* an ausländischen Tannenarten. Tharandfer Forstl. Jahrb., 89: 35-49.

Johnson, Norman E., Mitchell, Russell G., and Wright, Kenneth H.
1963. Mortality and damage to Pacific silver fir by the balsam woolly aphid in southwestern Washington. J. Forest. 61: 854-860, illus.

_____ and Wright, Kenneth H.
1957. The balsam woolly aphid problem in Oregon and Washington. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta. Res. Pap. 18, 34 pp., illus.

Keen, F. P.
1952. Insect enemies of western forests. U.S. Dep. Agr. Misc. Pub. 273 (revised), 280 pp., illus.

Mitchell, Russel G., Johnson, Norman E., and Rudinsky, Julius A.
1961. Seasonal history of the balsam woolly aphid in the Pacific Northwest. Can. Entomol. 93: 794-798.

Pope, Robert B.
1958. Cooperative evaluation survey of chermes damage, Mount St. Helens, Washington, 1957. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta., 25 pp.

Silver, G. T.
1959. The balsam woolly aphid, *Adelges piceae* (Ratz.) in British Columbia. Bi-Mon. Progr. Rep., Can. Dep. Forest., 15(1): 3.

Speers, Charles F.
1958. The balsam woolly aphid in the Southeast. J. Forest. 56: 515-516.

Whiteside, J. M.
1958. Forest insect conditions in the Pacific Northwest during 1957. U.S. Forest Serv., Pacific Northwest Forest & Range Exp. Sta., 49 pp., illus.

Mitchell, Russel G.
1966. Infestation characteristics of the balsam woolly aphid in the Pacific Northwest. U.S. Forest Serv. Res. Pap. PNW-35, 18 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

The balsam woolly aphid is a serious enemy of native and exotic true firs in Oregon and Washington. Grand, subalpine, and Pacific silver firs sometimes suffer severely from attack. Characteristics of infestations differ considerably between species and in different environments. Some exotics are not damaged.

Mitchell, Russel G.
1966. Infestation characteristics of the balsam woolly aphid in the Pacific Northwest. U.S. Forest Serv. Res. Pap. PNW-35, 18 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

The balsam woolly aphid is a serious enemy of native and exotic true firs in Oregon and Washington. Grand, subalpine, and Pacific silver firs sometimes suffer severely from attack. Characteristics of infestations differ considerably between species and in different environments. Some exotics are not damaged.

Mitchell, Russel G.
1966. Infestation characteristics of the balsam woolly aphid in the Pacific Northwest. U.S. Forest Serv. Res. Pap. PNW-35, 18 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

The balsam woolly aphid is a serious enemy of native and exotic true firs in Oregon and Washington. Grand, subalpine, and Pacific silver firs sometimes suffer severely from attack. Characteristics of infestations differ considerably between species and in different environments. Some exotics are not damaged.

Mitchell, Russel G.
1966. Infestation characteristics of the balsam woolly aphid in the Pacific Northwest. U.S. Forest Serv. Res. Pap. PNW-35, 18 pp., illus. Pacific Northwest Forest & Range Experiment Station, Portland, Oregon.

The balsam woolly aphid is a serious enemy of native and exotic true firs in Oregon and Washington. Grand, subalpine, and Pacific silver firs sometimes suffer severely from attack. Characteristics of infestations differ considerably between species and in different environments. Some exotics are not damaged.

The FOREST SERVICE of the
U. S. DEPARTMENT OF AGRICULTURE
is dedicated to the principle of multiple use management of the Nation's forest resources for sustained yields of wood, water, forage, wildlife, and recreation. Through forestry research, cooperation with the States and private forest owners, and management of the National Forests and National Grasslands, it strives — as directed by Congress — to provide increasingly greater service to a growing Nation.


NATIONAL FOREST SYSTEM
COOPERATIVE FORESTRY
FORESTRY RESEARCH
FOREST SERVICE
U.S.
DEPARTMENT OF AGRICULTURE